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Capsule Report: Environmental Controls at a Secondary Lead Smelter

Radian Corp., Austin, TX

Prepared for:

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16. ABSTRACT

The EPA and the National Institute for Occupational Safety and Health (NIOSH) have sponsored a study of environmental and workplace controls at a domestic secondary lead smelter. The study (described in this report) was intended primarily to develop information important to the effective control of environmental emissions and employee exposure. The study was carried out at East Penn Manufacturing Company in Lyons, PA. It comprised an initial baseline evaluation of environmental and workplace controls. In the followup sampling and analysis to characterize the East Penn lead smelter, the four major areas of interest were process source emissions, baghouse efficiency, employee exposure and workplace controls, and agglomeration furnace performance. Emission rates for specific lead smelting and refining operations were determined on sources hooded for emission control in the sanitary baghouse. These sources were sampled for total lead, total particle loading, and particle size distribution. Test results are reported for various sources upstream and downstream of the control systems. Employee exposures to airborne lead were reduced significantly after the control systems were in operation.

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Environmental Controls at a Secondary Lead Smelter

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This report was prepared jointly by the Centec Corporation of Reston VA and the Radian Corporation of Austin TX for the Industrial Environmental Research Laboratory in Cincinnati OH. Klaus Schwitzgebel and Robert Vandervort of Radian are the principal investigators. Alfred B. Craig, Jr., is the EPA Project Officer. Photographs were taken at East Penn Manufacturing Company in Lyons PA.

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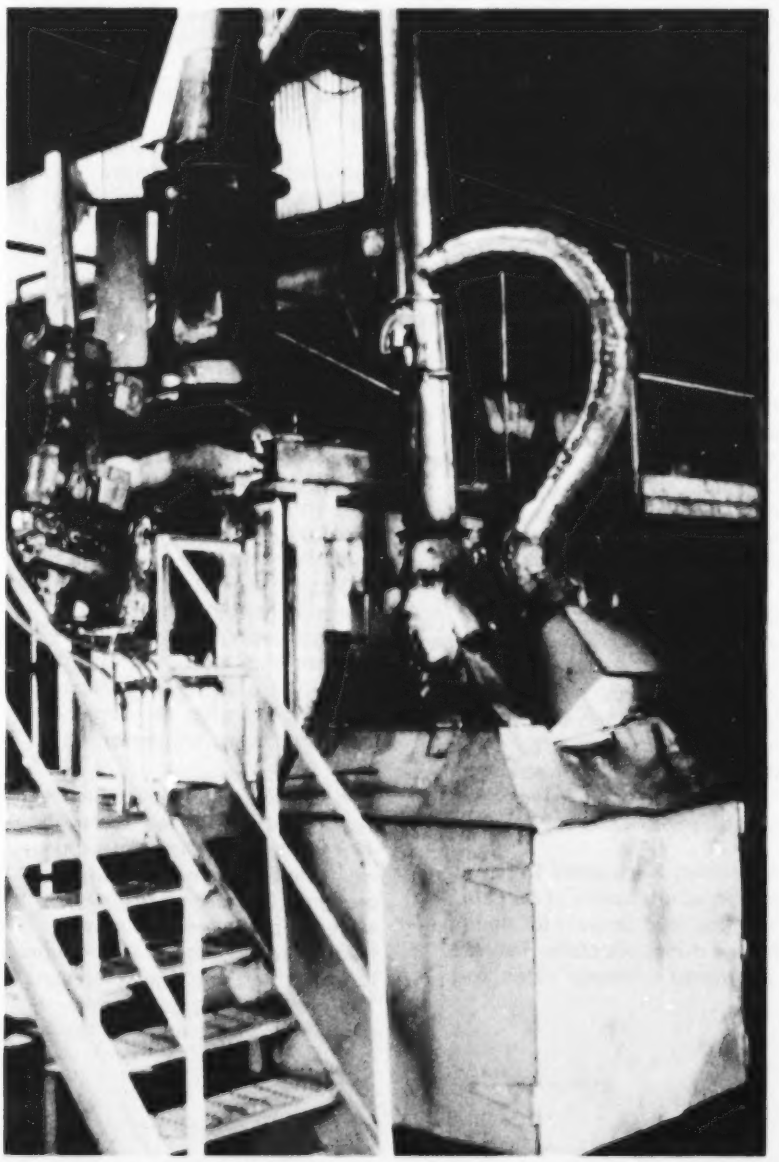
COVER PHOTOGRAPH: East Penn baghouse agglomerator building (left) and smelter (right)

1. Introduction and Summary

The Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA) have promulgated new standards for lead pollution in the air. The upper limit set by OSHA for airborne lead in the workroom is 50 $\mu g/m^3$; the EPA limit for ambient air at the plant fence line is 1.5 $\mu g/m^3$.

The EPA and the National Institute for Occupational Safety and Health (NIOSH) have sponsored a study of environmental and workplace controls at a domestic secondary lead smelter. The study (described in this report) was intended primarily to develop information important to the effective control of environmental emissions and employee exposure. The study was carried out at East Penn Manufacturing Company in Lyons, Pennsylvania. It comprised an initial baseline evaluation of environmental and workplace



Bergsøe agglomeration furnace

conditions at the East Penn smelter, and a followup evaluation after control measures had been implemented. The initial evaluation was performed in January 1979 and the followup evaluation—serving to document the design, operation, and effectiveness of the control systems—was conducted in August 1980.

East Penn's smelter was an ideal test site in that the company had previously decided to implement major pollution control measures at the facility. The measures were to include modifications to the exhaust ventilation system, major cleanup of smelter buildings and yard areas, paving of hitherto unpaved areas, installation of a central vacuum system, wetting of raw materials and work surfaces, and improved employee personal protective equipment and personal hygiene. East Penn also had made arrangements to purchase and install a Bergsøe agglomeration furnace for processing of flue dust that contains lead. The furnace—developed by Paul Bergsøe and Sons and installed at the Bergsøe smelter in Glostrup, Denmark—converts leady dust to a slaglike material and thereby helps to reduce lead emissions from dust handling.

During the followup evaluation, emissions captured by local exhaust ventilation were determined, complete with particle sizing analysis, for several smelting operations. A preponderance of small particles (smaller than 2.5 μm) was found. Table 1 gives captured lead emissions from specific operations.

Collection efficiencies were determined as a function of particle size and lead content for three baghouse dust collectors. Table 2 gives lead emission rates and baghouse efficiencies based on total particles.

Table 1.

Captured Lead Emissions from Major Process Steps: Followup Evaluations

Process	Rate (approximate)	
	Feed or production (Mg/d)	Emission (g/h)
Blast furnace:		
Charging	72.5	85,000
Slag tapping	12	900
Metal tapping	45.5	340
Refining	22.5	13
Ingot casting (pigging)	45.5	14
Flue dust agglomeration	3.5	50,000

Approximately 17,600 lb/d (8,000 kg/d) of flue dust containing lead was generated by heated smelting operations and collected in the three baghouse dust collection systems. Total lead emissions from smelter baghouse stacks were approximately 15 lb/d (7 kg/d).

Employee exposures to airborne lead were reduced significantly at several locations within the plant. After the control systems were in operation, exposure levels varied from 37 $\mu g/m^3$ at the battery breaking location to 410 $\mu g/m^3$ for the agglomerator operator. Note that these are local concentrations; overall ambient lead levels within the facility were 10 $\mu g/m^3$ before and 3 $\mu g/m^3$ after the control measures were implemented.

The agglomeration furnace operator's exposure to lead averaged 410 $\mu g/m^3$. This elevated exposure was caused by chronic operating problems in the dust-handling system—problems that allowed lead-containing flue dust and fumes to be emitted into the workplace. The dust-handling system at East Penn is different from the Bergsøe system in Glostrup, and furnace operation is hampered by the difference.

Upgrading local exhaust ventilation involved improvements in the design of enclosures around emission sources as well as increased exhaust rates. Local exhaust hood designs are discussed in Section 3. Over 30,000 $stdft^3/min$ (14 m^3/s) of additional exhaust capacity was added. The exhaust improvements were fabricated and installed at a cost of approximately \$11/$stdft^3$/min added capacity.

European car batteries contain polyvinyl chloride (PVC) as plate separators to a much larger extent than do batteries manufactured in the United States. Chlorine forms low-melting-point lead chloride phases that favor dust agglomeration. Recycling dust and adding chlorine to the furnace charge would help the furnace performance at East Penn.

The cooperation of East Penn's management facilitated the study program, as did a number of other factors:

- Hooding of individual process steps, which allowed quasi-stack measurements

Table 2.

Emission Rate and Efficiency of Baghouses: Followup Evaluation

Baghouse system	Emission rate (g/h)	Efficiency (%)
Slag-tapping baghouse	10	97.9
Sanitary baghouse system	84	99.9
Process gas treatment system	195	99.9

- Availability of flue dust from three different sources, which permitted comparison of agglomerating properties
- Documentation of local exhaust design features and performance characteristics
- Availability of control cost data

The study provided a significant body of information, including:

- Workplace contamination measurements before and after improved exhaust ventilation was installed
- Demonstration of Bergsøe's dust agglomeration technique at a U.S. secondary lead smelter
- Observation of the effects of improved housekeeping methods
- Workplace and environmental studies in combination, including particulate concentration measurements in particle sizes 2.5 to 15 μm and smaller than 2.5 μm.

2. Process Description

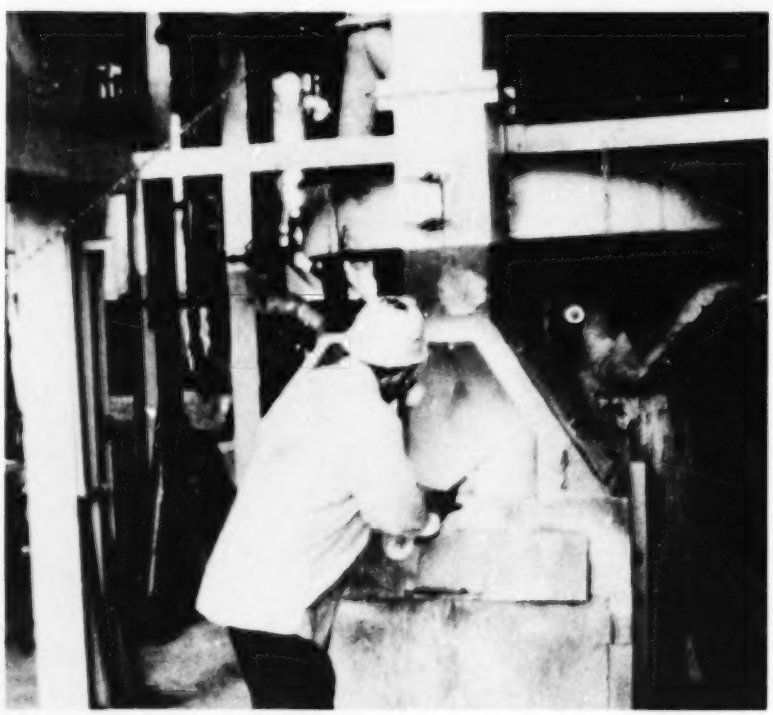
East Penn Manufacturing Company is a battery and cable manufacturer and secondary lead smelter. The firm makes both automobile and industrial batteries. Secondary lead is produced from used batteries and plant scrap when these materials are processed through a blast furnace and refining kettles. Figure 1 illustrates the flow of material at the time of the followup evaluation.

Scrap starting-lighting-ignition (SLI) batteries are delivered by truck and broken by means of a slow-moving hydraulic shear. Plastic casings are fed to the blast furnace along with the lead scrap. Rubber casings are separated and disposed of in a landfill.

Industrial batteries account for 5 to 10 percent of the blast furnace charge. The metal casings are opened with a torch and the cells are removed manually. The furnace charge consists of batteries and lead scrap, return slag, coke, iron, limestone, and silica in varying amounts. The charge is fed to the furnace with a skip hoist and is made up according to volume, depending on the individual charge components. Oxygen addition is regulated according to slag viscosity. The temperature of the furnace off-gases is monitored.

The blast furnace is of the vertical shaft type, 3.3 ft (1 m) in diameter and about 20 ft (6 m) high. The slag-and-lead collection pot on the bottom is manteled with fire resistant bricks. The upper part is double walled and water cooled. Slag is removed intermittently. The lead well flows almost continuously. The blast furnace produces about 50 tons/d (45 Mg/d) of lead and 20 tons/d (18 Mg/d) of slag, with about 4 to 8 tons/d (3.5 to 7.3 Mg/d) of dust.

Slag is poured into 1,300-lb (600-kg) slugs and disposed of after cooling. Lead is poured into water-cooled forms, producing 1,750-lb (800-kg) "hogs," which are then refined in



Slag tapping from blast furnace

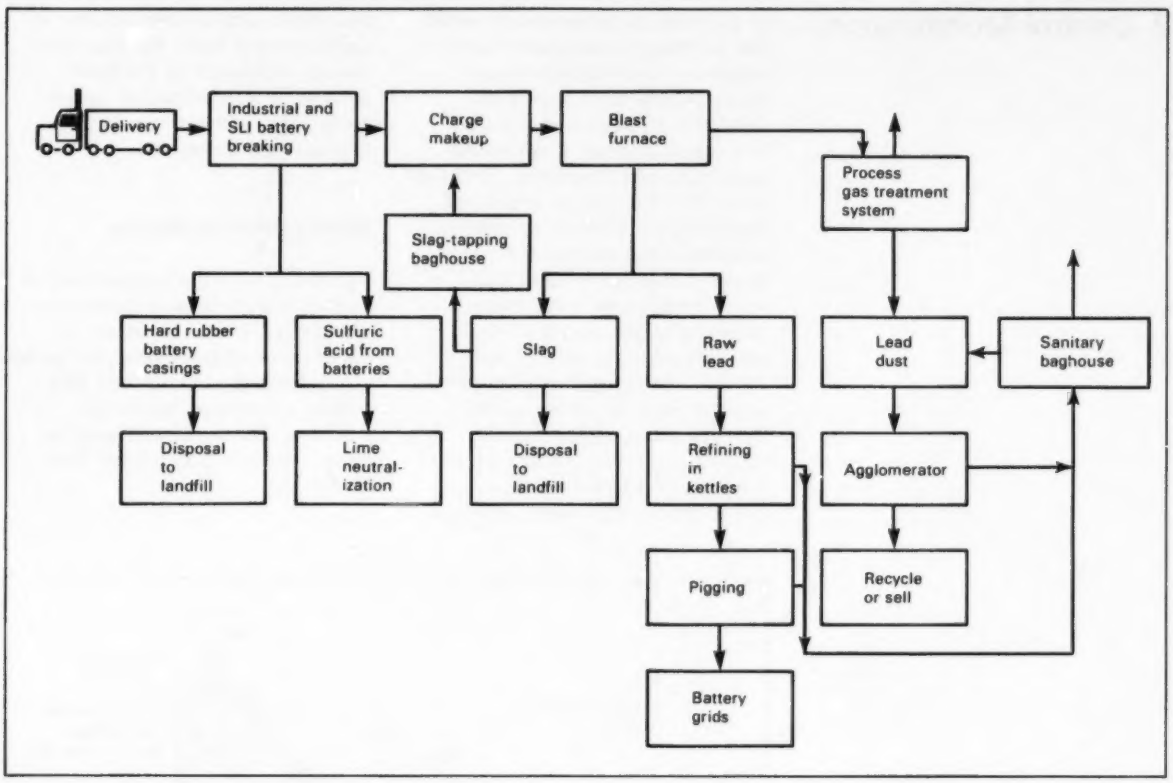


Figure 1.

Work Flow of Secondary Lead Smelter, East Penn Manufacturing Company: Followup Evaluation

one of two refining kettles. Reaction products and the refining waste, or dross, are skimmed and fed back to the blast furnace. After kettle refining, lead ingots or "pigs," weighing about 36 lb (16 kg), are cast in a mobile pigging machine that moves back and forth on tracks between two refining kettles.

Temperature and lead alloy composition are measured frequently during refining. The temperature of the pots is monitored intermittently and spectroscopic analyses give the composition before, during, and after kettling.

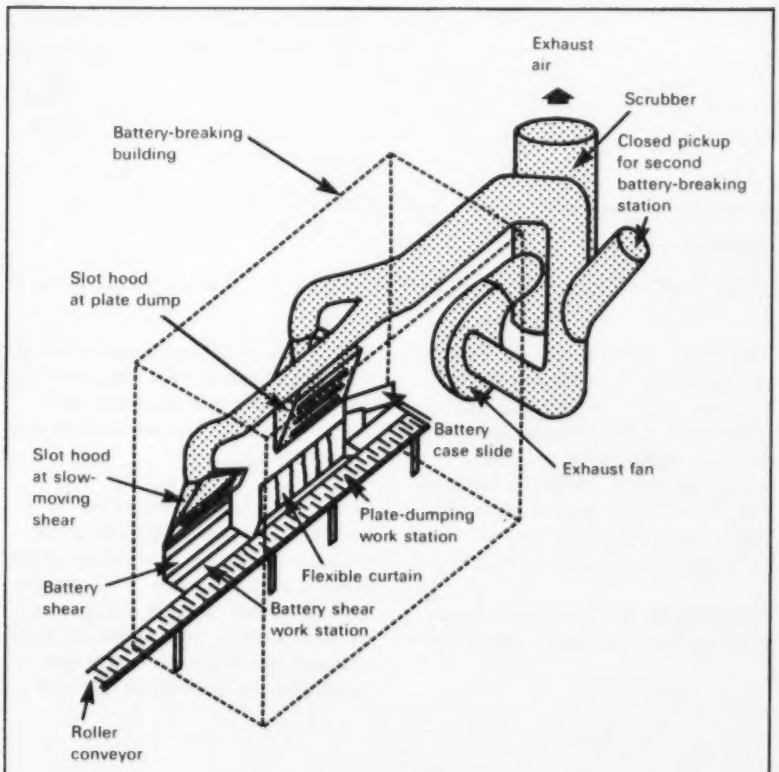
Individual process points are hooded. The particulate-laden off-gases are cleaned in three separate automated baghouses. Flue gases from the blast furnace are routed through various particulate removal devices and finally to a process baghouse. About half of the lead-containing flue dust collected by the process baghouse is agglomerated in a Bergsøe flash agglomeration furnace. The flue dust is fed to a sloping, heated hearth in this furnace. Lower-melting-point materials melt and run down the hearth, then through a tapping port to a crucible mold where they cool and solidify. The solid material is sold, along with non-agglomerated dust, to an outside company.

3. Control Modifications

In the interval between the initial and followup evaluations, several important modifications were made. A new baghouse dust collection system was installed to control sources of workplace lead-in-air contamination. This system extended new or improved local exhaust ventilation service to several operations. A local exhaust ventilation system was installed to serve the battery-breaking facility and a central vacuum-cleaning system was provided to serve smelting, refining, and dust-handling areas. A Bergsøe flash agglomeration furnace was installed to agglomerate the lead-bearing dusts collected in baghouses, knockout chambers, and U-tube coolers. In agglomerated form, the flue dust can be recharged to the blast furnace or transported to outside consumers without significant fugitive lead emissions.

Battery-Breaking Station

Figure 2 shows the battery-breaking station and its local exhaust ventilation system. This system is constructed of fiberglass-reinforced plastic and consists of two slot hoods, an exhaust fan, and a scrubber. The measured total exhaust rate was 6,200 stdft^3/min (2.9 m^3/s).



Note.—Exhaust system fabricated from fiberglass-reinforced plastic.

Figure 2.

Local Exhaust Ventilation for Battery-Breaking Station: Followup Evaluation

Blast Furnace

The local exhaust ventilation at the skip hoist used to charge the blast furnace was changed after the initial evaluation. A slotted configuration was added to the inside of the hood to increase its collection efficiency. Additional metal partitions were installed around the outside of the hoist to control loose accumulations of iron and flue dust. The total exhaust flow was increased from 1,390 $stdft^3$/min (0.66 m^3/s) to 1,700 $stdft^3$/min (0.81 m^3/s).

Figure 3 shows the exhaust ventilation enclosures provided at the top of the skip hoist and blast furnace. The slot hood over the furnace access doors was added following the initial evaluation. Exhaust air volumes were increased for these enclosures when the new sanitary baghouse became operational.

A separate baghouse exhaust ventilation system controls emissions from slag tapping. Between the initial and followup evaluations, an improved local exhaust enclosure was provided for the slag-tapping operation. The new enclosure more efficiently encapsulated the slag-tapping components, and the exhaust flow increased from 3,900 $stdft^3$/min (1.8 m^3/s) to 5,300 $stdft^3$/min (2.5 m^3/s).

Crude metal is tapped continuously from the blast furnace. Molten metal flows from the tapping hole through a lead well, then down a launder to water-cooled hog molds. Local exhaust ventilation is provided from the tap hole to mold pouring. Changes were made in the local exhaust ventilation control at the lead well, molten metal launder, and hog-casting station. The major change was the addition of hooding at the mold-pouring enclosures to trap and control emissions in these areas. Each exhaust enclosure features movable panels

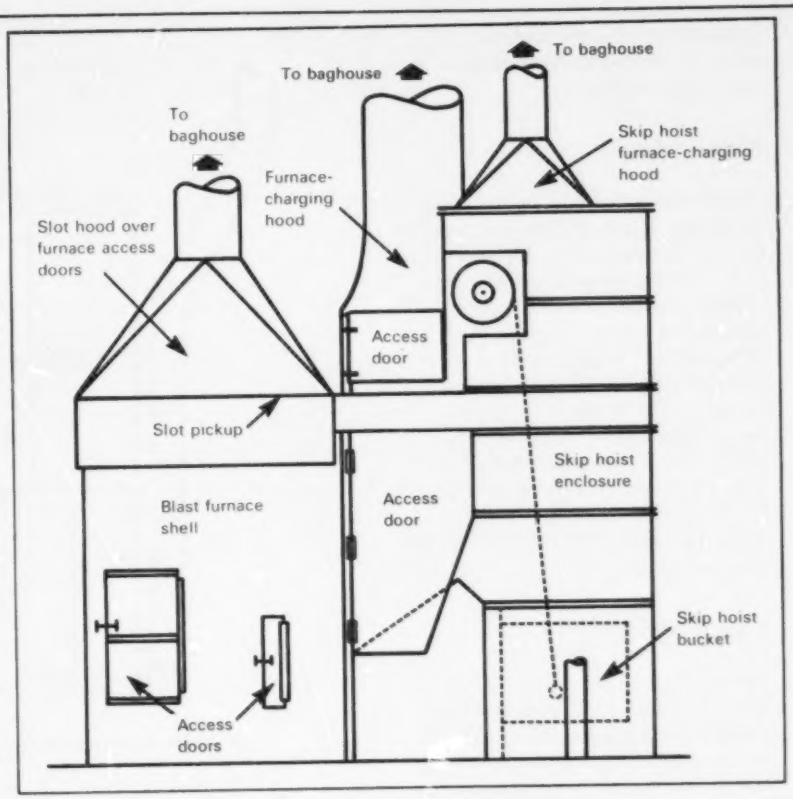
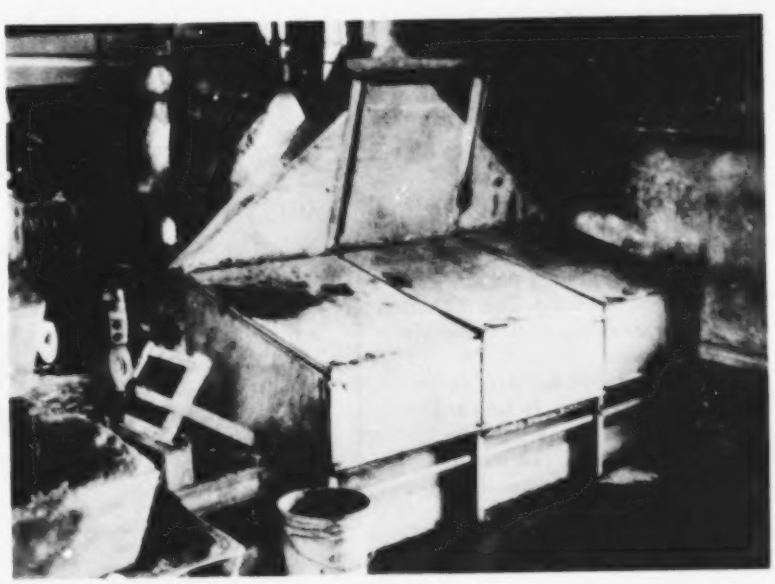


Figure 3.

Exhaust Hoods at Blast Furnace Charging Level: Followup Evaluation



Hooding for hog casting

or doors to facilitate material removal, cleaning, observation, and maintenance.

Refining Kettles

During the initial evaluation, only Kettle No. 1 was equipped with local exhaust ventilation. In the interim between the initial and followup evaluations, improved exhaust enclosures for both kettles were designed and installed. East Penn used its experience with the new hood for Kettle No. 1 to refine the design used in the hood for Kettle No. 2 (shown in Figure 4). This hood features metal access doors to allow passage of the monorail hoist, molten metal pump, and so forth.

Pigging Machine

During the initial evaluation, no local exhaust ventilation was provided for the pigging machine. Figure 5 shows the enclosing canopy hood installed on the pigging machine before the followup evaluation. This hood is connected to the new sanitary baghouse exhaust system through a flexible duct.

Agglomeration Furnace

Figure 6 shows the agglomeration furnace. The furnace is fed flue dust, which falls to a sloping hearth. The hearth is heated directly by a burner flame that causes the materials with lower melting points to melt and run down the hearth and through a tapping port to a hooded crucible mold. The material cools and solidifies in the crucible.

The agglomeration furnace, as installed at East Penn, is similar to furnaces in use at the Bergsøe smelter in Glostrup. The mechanism used to feed the furnace, the composition of the flue dust feed, and the operating temperature are distinct, however.

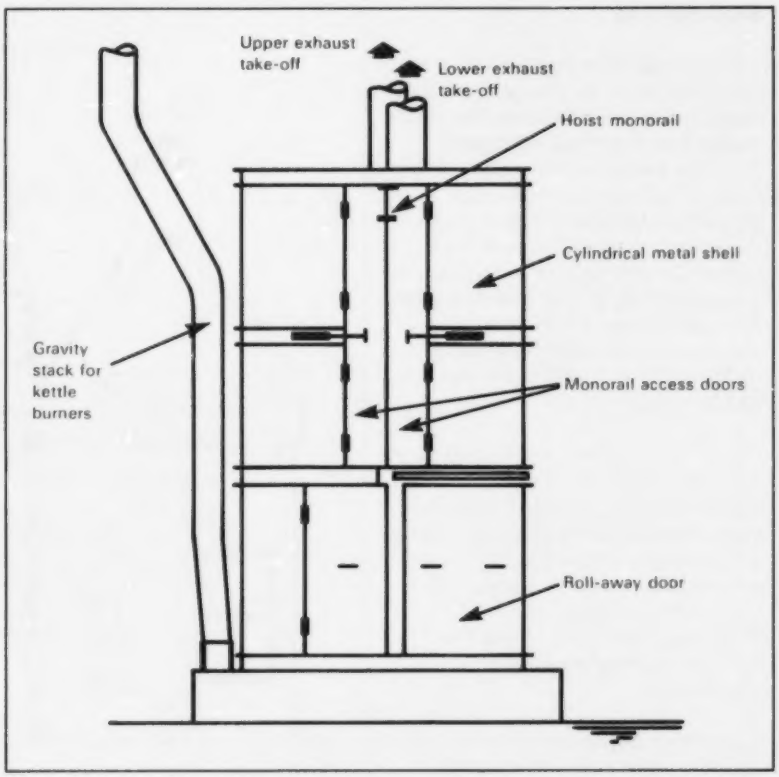


Figure 4.

New Exhaust Hood for Refining Kettle No. 2

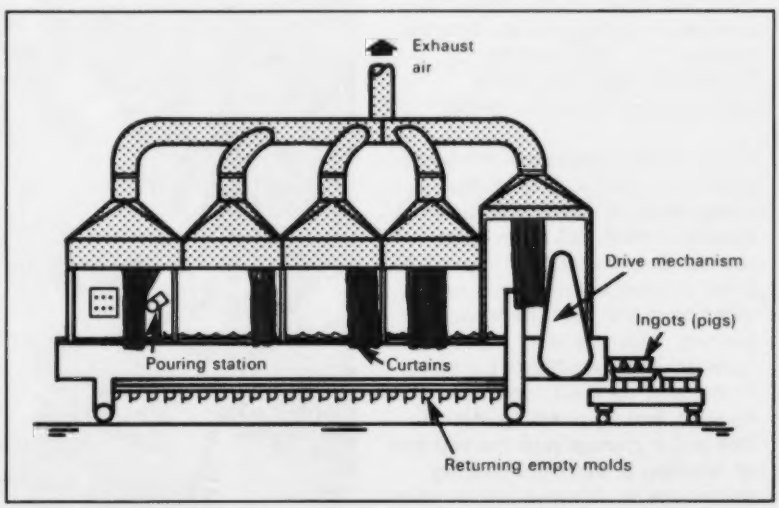


Figure 5.

Pigging Machine Canopy Hood

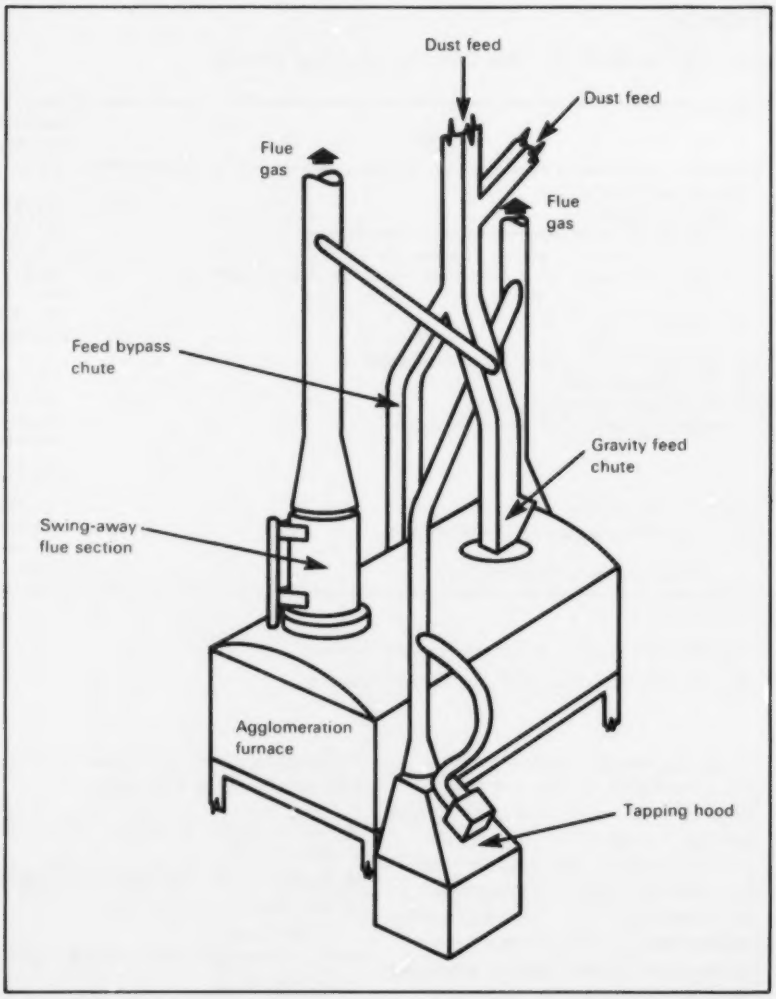


Figure 6.

Flue Dust Agglomeration Furnace

At the Bergsøe smelter, flue dust is moved by screw conveyor from the baghouse directly to the agglomeration furnaces. This approach results in a reasonably constant feed rate and facilitates stable furnace operation.

At the East Penn smelter, flue dust is collected in knockout chambers and baghouses that are physically separated from one another. No simple system of screw conveyors could be devised to collect dust from all collection points and feed it to the furnace. Also, it was feared that a screw conveyor connection to the furnace might increase the chance of a baghouse fire. A feed mechanism was devised that terminated in a gravity feed chute to the agglomeration furnace. This chute and its accompanying bypass are shown in Figure 6. The chute is fed by a system of bucket elevators and screw conveyors. The dust feed to bucket elevators can be shunted to tote boxes in the event of a breakdown or other problem.

Owing to inherent pulses caused by dumping the tote boxes and emptying the elevator buckets, the feeding of the furnace is not constant. The problem is aggravated by uneven dust drops when bags are shaken in various baghouse compartments, and by the tendency of the dust to clog the gravity feed chute. Clogging in the feed chute required that a vibrator be installed and that the chute be rodded manually.

Uneven feeding causes the furnace to operate unsteadily. Rapid dust feeding occasionally overwhelmed the furnace, requiring that the dust feed be stopped and the furnace high fired to clear its charge. In addition, a number of problems have been encountered in tapping the agglomeration furnace. Some are attributable at least in part to uneven feeding; others relate to the poor agglomerating properties of the flue dust at the East Penn smelter. The tapping spout repeatedly becomes clogged with material that is not fluid; an auxiliary burner has been installed to heat the spout.

Dust-Collection System

The emissions captured in the hoods are treated for particle removal in three baghouse systems:

- Slag-tapping baghouse
- Sanitary baghouse system
- Process gas treatment system

All three systems are operated automatically and individually. Observed pressure differentials are up to 8 in (20 cm) of water. Shaking cycles are approximately 1 h. Bag material is Orlon and Dacron fabric.

Slag-Tapping Baghouse. The slag-tapping baghouse is the smallest of the three baghouses, and controls only the emissions associated with slag tapping. This baghouse has a design capacity of 5,000 stdft^3/min (2.4 m^3/s). The cloth area is 7,500 ft^2 (700 m^2). The air-to-cloth ratio is 0.7:1. Dust collected, averaging about 585 lb/week (265 kg/week), is discharged to a tote box and transported to the dust storage area.

Sanitary Baghouse System. During the initial evaluation, emissions from sources other than the blast furnace slag tap and the blast furnace flue gas streams were collected by a hygiene exhaust air system and treated for particulate removal in a sanitary baghouse with 10,000 stdft^3/min (4.7 m^3/s) capacity. This baghouse was located on the roof of the building housing the employee locker room and lunchroom. The exhaust system did not serve the pigging machine, Refining Kettle No. 2, or the slot hood above the blast furnace access doors.

Following the initial evaluation, installation of a new sanitary baghouse was completed. This system has a rated capacity of 42,000 stdft^3/min (20 m^3/s) and a cloth area of 32,300 ft^2 (3,000 m^2). The air-to-cloth ratio is 1.3:1.

Ductwork from each exhaust hood is routed to a knockout chamber. A large duct connects the knockout chamber to the baghouse. The system collects approximately three tote boxes [about 1,540 lb (700 kg)] of flue dust containing lead each day. The dust is either transported to the agglomeration furnace by a bucket elevator system or collected in tote boxes and stored outside near the dust storage pile.

Process Gas Treatment System. The process gas treatment system treats the gases emitted from the blast furnace. The hot blast furnace offgas with a very high dust loading is drawn through a duct 4 ft (122 cm) in diameter to a dropout chamber where the biggest particles settle out. The offgas then passes through an afterburner for combustion of the organic pyrolysis products from battery casings and plate separators. The first cooling step occurs in a spray tower where the gas stream is split and flows through parallel banks of U-tube coolers. Exit gases from the U-tube coolers are combined in aftercoolers and routed to the lime station where hydrated lime is added as a fire retardant and, in case of acid condensation, as an acid neutralizer. Four bags of hydrated lime are used per shift. The feed is intermittent and manual. The process gas then enters the process baghouse, which has a capacity of 23,300 stdft^3/min (11 m^3/s) and a cloth surface area of 12,600 ft^2 (1,170 m^2). The air-to-cloth ratio is 1.8:1.

Table 3.

Summary of Costs for New East Penn Control System

Item	Installed cost ($)[a]
Improved ventilation system:	
Sanitary baghouse	163,050
Enclosure for baghouses and agglomeration furnace	97,231
Ductwork, dropout chambers, catwalks, etc.	113,392
Design, fabrication, and installation of exhaust ventilation enclosures	64,516
Total	438,189[b]
Flue dust agglomeration furnace and feeding system:	
License fee for furnace	25,000
Furnace and auxiliary equipment	38,023
Agglomeration furnace feeding equipment	43,247
Total	106,270[c]
Central vacuum system	20,250
Exhaust ventilation system for battery breaking	13,903
Total, new control system	578,612

[a]1979 dollars.

[b]Includes exhaust service for the agglomeration furnace.

[c]Excludes exhaust service for the agglomeration furnace.

Particulate removals in the process gas treatment system are:

- First dropout chamber, 585 lb/d (265 kg/d)
- Spray tower, 585 lb/d (265 kg/d)
- Air coolers, 2,340 lb/d (1,060 kg/d)
- Process baghouse, 15,400 lb/d (7,000 kg/d)

The dropout chamber and the spray tower are cleaned manually. Dust from the air coolers is transported to tote boxes by screw conveyors and discarded to the dust pile. Half the material from the process baghouse is fed to the Bergsøe agglomeration furnace, and half is stored at the outside dust pile.

General Housekeeping and Grounds Cleanup

At the time of the initial evaluation a large part of the smelter grounds was unpaved. Collected flue dust was stockpiled outside, where wind

and traffic spread the dust over the entire smelter area. Similarly, battery mud was tracked in and out of the buildings and heavy accumulations were present in yard areas. Dry sweeping techniques were used in many work areas.

A major cleanup program was implemented between the initial and followup evaluations. The yard was paved and large accumulations of flue dust and other lead-containing materials were removed. Wet cleaning methods were developed for several areas of the smelter. A central vacuum system was installed.

Through these efforts and those described earlier, lead concentrations in workrooms and in the breathing zones of workers have been reduced significantly. A gradual reduction in worker blood-lead levels has also been observed. Cleanup measures continue; for example, batteries stored outside are moved to sheltered areas. Constant attention to housekeeping is necessary because handling of broken batteries, screw conveying of flue dust, and so forth, remain as sources of lead contamination.

Costs of New Control Systems

During the followup evaluation, cost data were obtained from East Penn for the control modifications made at the smelter. Total installed cost of the new control system was $578,612. Table 3 gives individual cost items, organized in major categories.

Costs for materials or equipment and fabrication were primarily taken from vendor and fabricator invoices. Plant personnel estimated installation costs, using hourly wage rates for specific labor categories. All costs were derived in 1979 dollars.

4. Procedures and Results

In the followup sampling and analysis to characterize the East Penn lead smelter, there were four major areas of interest:

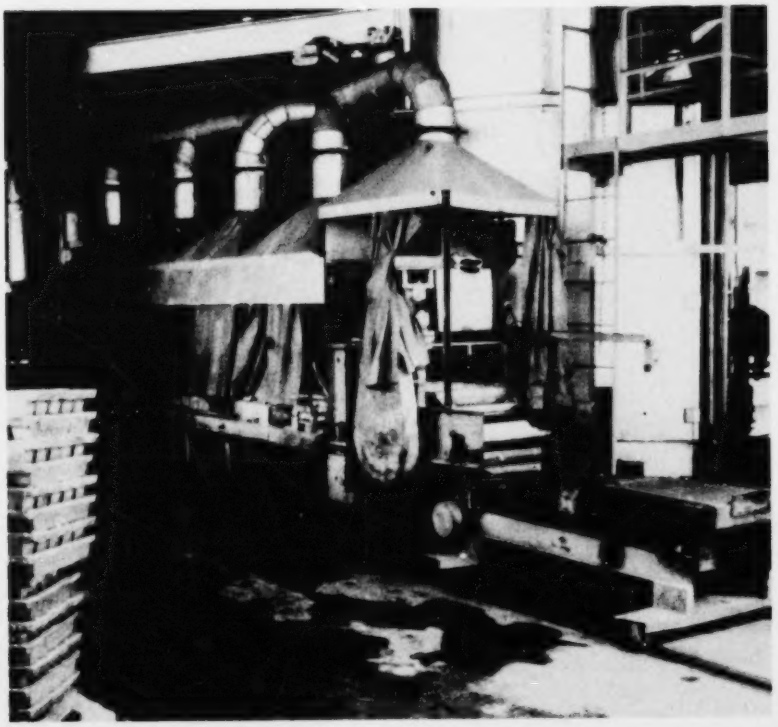
- Process source emissions
- Baghouse efficiency
- Employee exposure and workplace controls
- Agglomeration furnace performance

University of Washington impactors were used to measure the particle size distribution in individual internal process streams and baghouse stacks. Total particulate loading was measured according to EPA Method 12 (see Proposed New Source Performance Standards, *Federal Register,* 45:2790, Jan. 14, 1980). Filter treatment and method of lead analysis were compatible with accepted EPA and NIOSH recommendations.

Process Source Emissions

Emission rates for specific lead smelting and refining operations were determined on sources hooded for emission control in the sanitary baghouse. These sources were sampled for total lead, total particle loading, and particle size distribution. Samples were collected in each transfer line between the hood and the point at which the transfer line fed into the main transport line to the sanitary baghouse.

Table 4 gives the smelter source emission rates for total particulate matter and total lead. Blast furnace charging had the highest emission rate for both total particulate matter and total lead. Close behind were the emission rates of the agglomerator furnace. Total particles emitted by the slag-tapping process (1,300 and 1,800 g/h) were well below those emitted by the charging and agglomeration processes. Lead emission rates from slag tapping were 740 and 1,100 g/h on two consecutive days. Lead emissions from metal tapping fell close behind at 340 g/h. The pigging machine and the refining



Pigging machine with canopy hood

Table 4.

Emission Rates: Process Source Sampling and Baghouse Efficiency Sampling During Followup Evaluation

Source sampled	Sampling date (1980)	Stream flow rate (m^3/h)	Volume sampled (m^3)	Emission rates			
				Total particles		Lead	
				mg/m^3	g/h	mg/m^3	g/h
Process source sampling							
Blast furnace:							
Slag tapping	Aug. 5	7,000	1.3	190	1,300	108	740
	Aug. 6	6,800	1.2	270	1,800	160	1,100
Metal tapping	Aug. 12	18,000	2.9	31	570	19	340
	Aug. 15	18,000	2.8	53	950	NM	NM
Charging	Aug. 12	11,000	1.5	7,700	86,000	6,100	67,000
	Aug. 15	9,100	0.56	17,500	160,000	11,000	100,000
Agglomerator flue	Aug. 13	9,100	0.64	7,900	72,000	5,400	49,000
	Aug. 14	8,000	0.34	10,500	84,000	6,800	55,000
Refining kettle	Aug. 15	3,600	4.1	12	43	3.0	11
	Aug. 15 and 16	3,300	4	7.8	26	4.3	14
Pigging machine	Aug. 15	2,000	0.41	27	53	5.4	11
	Aug. 16	2,000	0.35	17	33	8.9	17
Baghouse efficiency sampling							
Slag-tapping baghouse:							
Inlet	Aug. 5	7,000	1.3	190	1,300	NM	740
	Aug. 6	6,800	1.2	270	1,800	NM	1,100
Outlet	Aug. 5	8,700	1.7	3.6	31	1	8.6
	Aug. 6	8,000	1.5	4.9	39	1.4	11
Process gas treatment system:							
Inlet	Aug. 7	4,300	0.28	24,000	106,000	18,000	79,000
	Aug. 8	4,400	0.11	130,000	570,000	110,000	430,000
Outlet	Aug. 7	33,000	2.8	25	830	7.4	240
	Aug. 8	33,000	2.6	8	260	4.5	150
Sanitary baghouse system:							
Inlet	Aug. 9	62,000	1.4	808	50,000	580	36,000
	Aug. 11	62,000	1.4	3,200	200,000	2,500	150,000
Outlet	Aug. 9	59,000	2.3	24	1,400	NM	NM
	Aug. 11	59,000	2.3	4.5	250	1.5	84

Note.—At 760 mm Hg and 20° C. NM = no measurement.

kettle had the lowest emission rates of the six processes.

The implementation of control systems resulted in a significant reduction in smelter emissions. However, it was beyond the scope of this study to determine the effects of the controls on the ambient air concentrations of particulate matter and lead.

Table 5 summarizes the particle size determinations for four of the six process sources. Particle size distributions were not determined for the pigging machine and the refining kettle because of the very low grain loadings in these operations. The total particulate matter and lead particles are grouped into three sizes:

- Small: smaller than 2.5 μm, for the inhalable size class
- Medium: between 2.5 and 15 μm, for the respirable range
- Large: larger than 15 μm

The blast furnace metal-tapping and agglomeration furnace emissions had a preponderance of small particles. The particles emitted by slag tapping were slightly more coarse (average of 33 percent large particles) and the charging area emissions were more coarse still (average of 71 percent large particles). In general, the size distributions of the lead particles closely followed the total particle size distributions except in the slag-tapping stream, where the lead particles were more heavily distributed to the smaller size fractions.

Table 5.

Particle Size Distribution: Process Source Sampling and Baghouse Efficiency Sampling During Followup Evaluation

Source sampled	Sampling date (1980)	Particle size distribution (% by weight)					
		Total			Lead		
		Small (<2.5 μm)	Medium (2.5-15 μm)	Large (>15 μm)	Small (<2.5 μm)	Medium (2.5-15 μm)	Large (>15 μm)
Process source sampling							
Blast furnace:							
Slag tapping	Aug. 5	32	33	35	82	11	7
	Aug. 6	53	15	32	74	10	16
Metal tapping	Aug. 12	83	8	9	83	5	11
	Aug. 15	NM	NM	NM	NM	NM	NM
Charging	Aug. 12	17	1	82	25	9	66
	Aug. 15	29	11	60	39	6	55
Agglomerator flue	Aug. 13	78	19	3	73	25	2
	Aug. 14	69	19	12	70	19	11
Baghouse efficiency sampling							
Slag-tapping baghouse:							
Inlet	Aug. 5	32	33	35	82	11	7
	Aug. 6	53	15	32	74	10	16
Outlet	Aug. 5	60	18	22	78	19	3
	Aug. 6	64	36	0	69	28	3
Process gas treatment system:							
Inlet	Aug. 7	NM	NM	NM	NM	NM	NM
	Aug. 8	NM	NM	NM	NM	NM	NM
Outlet	Aug. 7	73	20	7	76	20	4
	Aug. 8	66	24	10	70	26	4
Sanitary baghouse system:							
Inlet	Aug. 9	22	2	76	34	7	59
	Aug. 11	34	4	62	36	12	52
Outlet	Aug. 9	59	27	14	84	15	1
	Aug. 11	71	25	4	52	29	19

Note.—Calculated from University of Washington impactor runs. NM = no measurement.

The preponderance of small particles can be explained by the volatilization of lead compounds at elevated temperatures. Lead compounds evaporated at high temperature regimes of the melting process will condense as the gases cool. The formation and enrichment of lead in small particles is the consequence. Particles in the range of 1 μm prevail.

Baghouse Efficiency

Collection efficiencies for total particulate matter and as a function of particle size were determined for the slag-tapping baghouse, sanitary baghouse, and process gas treatment baghouse. The results of the baghouse efficiency and emission rate measurements for all three baghouses are given in Table 4. Table 5 gives particle size data for inlet and outlet streams for all three.

The efficiency of the slag-tapping baghouse in removing particulate matter averaged about 98 percent for the two sampling periods. Lead particle collection efficiency averaged 99 percent. The result was an average lead emission rate from the stack of 9.8 g/h.

The inlet to the sanitary baghouse was sampled after the sanitary gas knockout chamber and after all the following ventilation systems were mixed:

- Blast furnace charging
- Blast furnace metal tapping
- Refining kettles
- Pigging machine
- Agglomerator flue

Sanitary baghouse collection efficiencies for total particulate matter averaged 99.3 percent for the two sampling runs. On August 11, 1980, collection efficiency for lead was 99.9 percent.

The collection efficiency determined for the process gas treatment baghouse represents the combined collection efficiencies of the following devices, listed in sequence:

- Knockout chamber immediately after the inlet sampling location
- Afterburner for combustion of organics
- Second knockout chamber
- Cooling tubes
- Dry lime injection immediately before the process gas treatment baghouse
- Process gas treatment baghouse

Each of these devices contributed to the removal of particles from the process gas stream; all are included in the final collection efficiency determination.

The results given in Table 4 show an average collection efficiency of 99.8 percent for the two sampling periods. Lead collection efficiency averaged 99.9 percent.

Data in Table 5 indicate that the particle size distribution in the process baghouse outlet was skewed to the smaller size. Seventy percent of the total particles and 73 percent of the lead particles were in the small size category.

Employee Exposure and Workplace Controls

A basic objective of the initial and followup evaluations was an assessment of the effectiveness of the program for control of smelter employees' exposure to lead. Of specific interest was the correlation of a reduction in employee exposure with improved engineering controls, use of protective clothing and equipment, and improved housekeeping and personal hygiene.

Limited personal exposure monitoring was performed as part of the initial and followup evaluations.

Table 6.

Comparison of Time-Weighted Average Lead-in-Air Exposures: Initial and Followup Evaluations

Job title	Time-weighted average lead-in-air concentration ($\mu g/m^3$)[a]	
	Initial evaluation	Followup evaluation
Furnace operator	620	150
Hoist operator	2,200	130
Payloader operator	860	160
Cokeman	400	110
Potman	260	80
Foreman	600	160[b]
Industrial battery breaker	500	96
Cleanup staff (general)	400	72
Battery breaker	1,500	37
Agglomerator operator	—	410
Cleanup staff (agglomerator)	—	150

[a]Concentration for all job time sampled during 2 days of monitoring: initial evaluation, Jan. 23 and Jan. 24, 1979; followup evaluation, Aug. 5 and Aug. 7, 1980.

[b]Foreman assisted agglomerator operator.

Exposures were measured in accordance with NIOSH and OSHA procedures. Airborne lead was collected from worker breathing zones with 0.8-μm pore-size cellulose ester membrane filters held in closed-face plastic cassettes. Personal sampling pumps provided air sampling rates between 0.05 and 0.07 ft^3/min (1.5 and 2.0 L/min). Flow rates were monitored with a precision rotameter calibrated against a bubblemeter before and after each day's sampling.

Samples were analyzed by atomic absorption spectrophotometry in basic accordance with NIOSH Method No. P & CAM 173 (see the second edition of *NIOSH Manual of Analytical Methods,* 1979). Some of the samples were wet ashed, and perchloric acid was added to the routine nitric acid ashing solution. During the followup evaluation, perchloric acid was shown to have no beneficial effect on the analyses.

A comparison of data from the initial and followup evaluations confirms that exhaust ventilation systems and housekeeping are important means of controlling employee exposure in a secondary lead smelter.

Table 6 compares lead exposures for specific jobs during the initial and followup evaluations. The exposure values given are time-weighted average concentrations. Lead-in-air concentrations were much lower during the followup evaluation, with agglomerator operation the only job involving exposure above 200 $\mu g/m^3$.

Table 7 compares exhaust air flows associated with workroom exposure controls during the initial and followup evaluations. The upgraded exhaust systems provided greatly increased air flows at nearly all exhaust hoods.

Table 8 compares exhaust hood performance during the initial and followup evaluations. Face velocities, capture velocities, and hood entry coefficients were generally much improved.

Table 7.

Comparison of Exhaust Air Flows Associated with Workroom Exposure Controls: Initial and Followup Evaluations

Exhaust hood	Flow rate (m^3/s)	
	Initial evaluation[a]	Followup evaluation
Battery breaking:		
Shear exhaust hood	NC	1.4[b]
Plate-dumping hood	NC	1.5[b]
System total	NC	2.9[b]
Blast furnace:		
Skip hoist hood (ground level)	0.66	0.8
Skip hoist furnace-charging hood	1.7	1.9
Furnace-charging hood		3.2
Slot hood over furnace access doors	NC	0.34
Slag-tapping hood (separate baghouse)	1.8[b]	2.5[b]
Metal-tapping hood	0.66	2.2
Launder hood	0.39	0.9
Hog-casting hood	0.30	2.2
Refining kettles:		
Exhaust hood, Kettle No. 1	0.71	1.0
Exhaust hood, Kettle No. 2	NC	1.6
Pigging machine: Canopy hoods	NC	0.94
Agglomeration furnace:		
Flue gas stream and dust feed exhaust control	NC	2.8
Tote box dumping hood	NC	0.31
Tapping hood	NC	0.36
Total measured flow (sanitary baghouse)	4.4[c]	18[d]

[a]NC = not constructed.

[b]Airflows are part of independent exhaust system; not included in total measured flow.

[c]Total to old exhaust system; excludes flows to independent exhaust systems. Baghouse above employee locker room.

[d]Total to new exhaust system; excludes flows to independent exhaust systems.

Housekeeping practices at East Penn improved between the initial visit and the followup surveys. The plant yard and roadways were paved with asphalt and a mobile sweeper-vacuum is used to keep these areas clean.

A central vacuum system was installed to service the smelter building, the agglomerator building, and the yard between the two. Water hose-bibs, a concrete floor, and a central floor drain were installed in the agglomerator building. A metal partition was built for partial separation of the charge preparation and smelting areas of the main smelter building. The number of workers routinely assigned to cleanup duties each shift was increased. The lunchroom was scheduled for daily janitorial attention. These changes resulted in a greater level of control for settled dust and fume particles.

A problem occurs, however, with the use of water for cleanup. Water alone is not an effective wetting agent for the lead dusts. The dust-water mixture is slippery and can create a hazard on walking surfaces. Spraying water on piles of lead flue dust actually stirs up the dust and redisperses it into the air. Also, washing down floors and roadways with water is not practical in the winter owing to the formation of ice. It is possible that a wetting agent could be added to the washdown water to alter the hydrophobic surface of the lead dusts, but this action would not solve the problem of ice formation.

Agglomeration Furnace Performance

Operational difficulties of the Bergsøe agglomeration furnace at East Penn prompted an investigation to characterize chemical composition and physical properties of lead dusts from different secondary smelters. Dust for this study came from the smelters at East Penn, Bergsøe in Glostrup, and General Battery Corporation in Reading, Pennsylvania.

Lead, chlorine, and potassium were found in the concentrations shown in Table 9. Calcium and iron were also found in high concentrations.

The higher chlorine and potassium values in the General Battery and Bergsøe samples are noteworthy. Chlorine originates from chlorine-containing polymers introduced with the battery casings and plate separators. The source of potassium is unknown.

It is worthy of note that, among other constituents, elemental lead was contained in the East Penn sample, lead chloride was a minor constituent in the General Battery sample and a major constituent in the Bergsøe sample, and a moderate concentration of potassium lead chloride (as KPb_2Cl_5) was found in the Bergsøe dust. The apparent differences can be explained by variations in the charge materials at the three smelters, and by a difference in furnace operation.

Table 8.

Comparison of Exhaust Hood Performance: Initial and Followup Evaluations

Exhaust hood	Initial evaluation[a]			Followup evaluation[b]		
	Exhaust flow (m^3/s)	Face or capture velocity (m/s)	Hood entry coefficient (Ce)[c]	Exhaust flow (m^3/s)	Face or capture velocity (m/s)	Hood entry coefficient (Ce)[c]
Battery breaking:						
Shear exhaust hood	NC	NC	NC	1.4	v_c,0.61	0.57
Plate-dumping hood	NC	NC	NC	1.5	v_c,0.66	0.54
Blast furnace:						
Skip hoist hood (ground level)	0.66	[d]	NM	0.8	v_f,0.25-0.5	0.9
Skip hoist furnace-charging hood	1.7	NM	NM	1.9	NM	0.59
Furnace-charging hood				3.2	NM	NM
Slot hood over furnace access doors	NC	NC	NC	0.34	v_f,2.5-3	0.58
Slag-tapping hood	1.8	NM	0.47	2.5	v_c,2.5-5.1	0.75
Metal-tapping hood	0.66	v_f,0.5-1	0.71[e]	2.2	v_f,2.5-4.1	0.89
Launder hood	0.39	v_f,<0.25-1	0.3	0.9	v_f,2.5-4.1	0.54
Hog-casting hood	0.3	v_f,<0.25	0.47	2.2	v_f,0.75-1.8	0.63
Refining kettles:						
Exhaust hood, Kettle No. 1	0.71	v_f,0.5-1	0.67-0.73	1	[d]	NM
Exhaust hood, Kettle No. 2	NC	NC	NC	1.6	NM	NM
Pigging machine: Canopy hoods (curtains closed)	NC	NC	NC	0.94	v_c,0.25-0.5	0.48
Agglomerator furnace	NC	NC	NC			
Flue gas stream and dust feed exhaust control	NC	NC	NC	2.8	NM	NM
Tote box dumping hood	NC	NC	NC	0.31	NM	0.25
Tapping hood	NC	NC	NC	0.36	v_f,1.3-1.5	0.32

[a]Data collected in Jan. 1979.

[b]Data collected in Aug. 1980.

[c]$Ce = \sqrt{VP/SP_h}$, where VP = dynamic pressure, and SP_h = hood static pressure.

[d]Room air currents stronger than draft induced in hood.

[e]Draft gate directly above hood partly closed.

Note.—NC = not constructed. NM = no measurement.

Table 9.

Lead, Chlorine, and Potassium Concentrations in Dust from Three Secondary Smelters

Smelter	Concentration (%)		
	Lead	Chlorine	Potassium
East Penn Manufacturing Company Lyons, Pennsylvania	64-99	1-3	0.3
General Battery Corporation Reading, Pennsylvania	53	8.5	1.3
Paul Bergsøe and Sons Glostrup, Denmark	60-65	24-26	3-4

The quantities and types of chloride compounds in the dust have a pronounced influence on agglomeration properties. The lead chloride melt readily wets higher melting point lead compounds like lead oxide and lead sulfide. Because elemental lead does *not* wet lead oxide and lead sulfide, a two-phase system results upon resolidification.

Battery plates are separated by nonconductive materials, among them PVC. It is estimated that, in the United States, only 3 percent of the automobile batteries contain PVC separators. In Europe, however, 25 to 30 percent of the automobile batteries contain PVC separators. This difference has an important consequence in that much less chlorine is introduced into secondary lead smelters in this country than is the case in Europe. The result is the difference in dust composi-

tions and, therefore, in agglomeration properties observed at East Penn and Bergsøe. Consequently, European technology may not transfer to U.S. operations without some alteration or development work.

The lead chloride concentration can build up continuously if the agglomerated dust is recycled to the blast furnace. The rate of buildup depends on the rate at which the compound forms, which in turn depends on the chloride content in the feed materials. Ultimately, a slip stream of the baghouse dust may need to be treated to remove lead chloride. At 68° F (20° C), lead chloride has a solubility of 10 g/L; at 212° F (100° C) the solubility is 33 g/L. Aqueous leaching, therefore, would be a feasible method of removing lead chloride.